Neural Substrates of Specialized Knowledge Representation: An fMRI study

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ABSTRACT

Brain-imaging techniques can be applied in specialized language research to provide insights into how specialized concepts are represented, and processed in the brain. The fMRI study described in this paper focused on general and specialized lexical units and the perception of semantic meaning by expert geologists and non-geologists. The subjects performed semantic matching tasks and made decisions in regards to general language words and specialized terms designating specialized tools and familiar household utensils. The linguistic processing of specialized terms was found to be modulated by the individual's previous experience with the objects. These results strengthen the hypothesis that when performing a domain-specific task, experts activate different brain systems from novices. This provides data regarding which brain systems are involved in cognitive processes.

Keywords: specialized knowledge, fMRI, terminology, expertise

RESUMÉ

Les techniques d'imagerie cérébrale peuvent être employées dans la recherche des connaissances spécialisées afin de découvrir la façon dont les concepts spécialisés sont représentés dans le cerveau. L'étude d'IRMf décrite dans cet article porte sur la perception des unités lexicales générales et spécialisées, ainsi que de leurs significations sémantiques, chez des sujets spécialistes en géologie et des sujets non-experts. Les sujets ont effectué des tâches d'appariement sémantique par rapport à des mots de la langue générale et à des termes spécialisés faisant partie de la catégorie sémantique des instruments, soit ménagers ou spécialisés. Les résultats indiquent que le traitement des termes spécialisés repose sur l'expérience préalable des sujets avec l'objet, ce qui confirme l'hypothèse que, lors de l'exécution d'une tâche spécialisée, les spécialistes activent une partie du cerveau différente de celle utilisée par les non-experts. L'expérience nous a permis d'obtenir des données significatives sur les systèmes cérébraux impliqués dans ces processus cognitifs.

Mots clés: connaissances spécialisées, IRMf, terminologie, expertise

1. Introduction

As a discipline, Terminology overlaps to some extent with Semantics, Lexicography, and Cognitive Science since one of its main focuses is the representation of specialized concepts within a certain knowledge domain. One of the practical applications of

Terminology is the design and creation of specialized knowledge resources so that users can effectively access concepts and associated information in order to acquire specialized knowledge (Faber *& al*. 2014). Such resources are often based on explicit or implicit conceptual representations.

This emphasis on concept networks in Terminology stems from the premise that specialized knowledge understanding is enhanced when terms are organized so that the relations between them are made explicit (Budin 1994; Meyer *& al.* 1997). This presumably facilitates the activation of associative information in semantic memory, thus promoting context availability. The underlying assumption is that new knowledge is more meaningful when it is related to previous knowledge. Consequently, for concepts to become a part of one's knowledge and be retained in long-term semantic memory, they must be embedded within a knowledge structure (Faber 2011, 2012; León-Araúz *& al.* 2012). Since the design objective of a knowledge resource should reflect the way that specialized knowledge is stored, organized, and retrieved by an expert in the field, the conceptual configuration of terms in specialized knowledge resources is necessarily based on assumptions regarding how this occurs in the human brain.

In cognitive neuroscience, there is now a large body of work that explores whether and to what degree sensory and motor information is a part of semantic representation and processing (Meteyard *& al.* 2012). Theories that support this view can be ranged on a continuum. At one end are mainstream theories that claim that semantic information is symbolic and encoded in a common representational format, independent of sensory and motor systems (Quillian 1969; Anderson 1983). At the other end are strongly embodied theories positing that concepts are totally grounded in perception and action, and thus are completely dependent on sensory and motor systems (Gallese & Lakoff 2005). Nevertheless, reality probably lies somewhere in-between (Meteyard *& al.* 2012; Kiefer & Pulvermüller 2012). This is the view of Patterson *& al.* (2007), who propose a supramodal format for semantic representations, which is modality-invariant though derived from mappings across sensory and motor input.

Although the neurolinguistic substrate of specialized knowledge processing and representation is still relatively unexplored, brain-imaging techniques can be applied to obtain insights into how concepts are represented and processed in the brain. They can also supply clues as to how semantic processing is carried out, and provide data related to the nature of specialized knowledge representations in semantic memory. Another issue is whether the information activated by experts in a certain field is different from that activated by non-experts. The clarification of these questions would have an impact on the structure of terminological knowledge bases as well as on terminological definitions. Evidently, a more realistic view of what occurs in the brain during semantic processing would be a valid starting point for the creation of conceptual networks in knowledge bases with a better claim to psychological adequacy.

The fMRI study performed focused on general and specialized lexical units and the perception of semantic meaning by a group of expert geologists and a group of non-geologists. In the conceptual task, the subjects made semantic matching decisions in regards to general language words and specialized terms. Our hypothesis was that the experts would activate different brain areas from non-experts.

In what follows, Section 2 describes the participants, experimental paradigm, data acquisition procedure, MRI parameters, and analysis. Section 3 presents the results obtained, and finally, Section 4 discusses the significance of these results within the context of specialized knowledge processing and representation.

2. Materials and methods

2.1. Participants

Five expert geologists and five non-geologists participated in this study. All of them were right-handed males with native fluency in Spanish. Table 1 shows the socio-demographic information. The geologists were recruited from the Spanish National Research Council and the Geology Department of the University of Granada. All had worked as geologists for over 20 years and were still working at the time of the study. Approximately, 25% of their time was devoted to field studies. The non-experts were recruited from the social sciences and humanities departments of the university. All subjects coincided in the main demographic variables. The data in Table 1 show that although the number of participants was relatively low, the results of the study can be generalized to a certain degree because of the homogeneity of the participants.

Table 1. Demographic characteristics

	Expert (n = 5) Mean (SD)	**Non-expert (n = 5) Mean (SD)**	**p-value**
Age (years)	59 (8.86)	54.8 (8.53)	0.464
Years of education	21 (0.00)	19.8 (2.68)	0.374

SD: Standard Deviation

The inclusion criterion for all participants was that they were able to read fluently. Exclusion criteria were the presence of a history of head injury and neurological, infectious, systemic or any other diseases affecting the central nervous system as well as the presence of significant abnormalities in Magnetic Resonance Imaging (MRI) or any contraindications to MRI scanning (including claustrophobia and implanted ferromagnetic objects). All participants had normal or corrected-to-normal vision. The study was approved by the Ethics Committee for Research in Humans of the University of Granada (Spain). All participants signed an informed consent form certifying their voluntary participation.

2.2. Experimental paradigm

In the experimental task, participants had to select a word related to a target stimulus. The stimuli appeared at the top of the screen with four possible answers (see Table 2).

Table 2: Examples of questions

Specialized term association	
Goniómetro [Goniometer] a. mol [mole] b. área [area] c. ángulo [angle] d. No sé [I don't know]	Cromatógrafo [Chromatograph] a. unión [union] b. coordinación [coordination] c. separación [separation] d. No sé [I don't know]
General language word association	
Reloj [Watch] a. tiempo [time] b. espacio [space] c. calibre [caliber] d. No sé [I don't know]	Tijeras [Scissors] a. dibujar [draw] b. esquivar [dodge] c. recortar [cut] d. No sé [I don't know]

As shown in Table 2, the stimulus consisted of a specialized geological term or a general language word and four possible answers, one of which was semantically related to the stimulus. For example, *goniómetro* [goniometer] is linked to *ángulo* [angle] by the semantic relation *measures*. The same relation also links *reloj* [watch] and *tiempo* [time]. The stimulus and correct answer were linked by one of the following semantic relations: *has_attribute* (e.g. hydrometer, floating), *has_function* (e.g. chromatograph, separation), *measures* (e.g.. oscilloscope, signal), *has_part* (e.g. collimator, lens) and *has_patient* (e.g.. penetrometer, subsoil).

The four possible answers belonged to the same part-of-speech category (noun or verb) and general semantic category (entity or action). For instance, the possible answers for *goniómetro* [goniometer] and *reloj* [watch] are all nouns referring to magnitude. Those for *cromatógrafo* [chromograph] are nouns designating function, and those for *tijeras* [scissors], verbs designating function.

The participants used a response pad to select the answer that was most closely related to the specialized term or general language word on the screen. To avoid random guessing, the subjects were told that the last choice on the list was “No sé” [I don’t know], and that they should choose this option if the stimulus was unfamiliar to them. In the experiment, the target stimuli were 64 instruments or tools: 32 highly technical geological instruments (specialized terms) and 32 familiar household utensils (general language words). The target stimuli were instruments and tools because they are self-contained tangible objects that entail interaction and used by humans for some purpose.

The terms had been selected from the instruments in the EcoLexicon database (ecolexicon.ugr.es) and other earth science resources, such as geological dictionaries and laboratory catalogues. The answers were extracted from dictionary definitions as well as collocates in corpus concordance lines. Since each item appeared on the screen for eight seconds, regardless of the response time, the task lasted for 8 minutes and 32 seconds. The trial types were pseudo-randomized to prevent the participant from being able to predict whether the following item was a word or a term.

The subjects were interviewed at the end of the task, and asked whether the questions had been difficult or ambiguous, and whether there was sufficient time to answer. The expert subjects were also asked about their geological work and the relevance of the specialized terms. All of the subjects confirmed that they had understood and correctly followed the instructions given before the task and that the questions were unambiguous and easy to answer.

2.3. *Data acquisition procedure*

Participants arrived 20 minutes before the scanner session to receive instructions and to learn how to use the response pad. They were informed of the difference between a specialized term and a general language word, and they were also reminded to use the "I don't know" option when necessary. The task was performed with Presentation software (Neurobehavioral System Inc., San Francisco, CA). The items were presented through magnetic resonance-compatible liquid crystal display goggles (Resonance Technology, Northridge, CA, USA) equipped with various corrective lenses. Behavioral responses were recorded by means of a five-button box, Evoke Response Pad System (Resonance Technology Inc.) positioned on the participants’ chest. For each item, participants selected an option with their right hand: the first option was selected with the index finger, the second option with the middle finger, the third with the ring finger, and the fourth with the little finger.

2.4. ***MRI parameters***

The equipment used was a 3.0 Tesla clinical MRI scanner with an eight-channel phased-array head coil (Intera Achieva, Philips Medical Systems, Eindhoven, The Netherlands). During acquisition, two T2*-weighted echo-planar imaging (EPI) were obtained (Repetition time (TR) = 2000 msec, Echo time (TE) = 35 msec, Field of view (FOV) = 230 x 230 mm, 128 x 128 matrix, flip angle = 90°, 22 4-mm axial slices, 1-mm gap, 330 scans each). A sagittal three-dimensional T1-weighted turbo-gradient-echo sequence (3D-TFE) (160 slices, TR = 8.3 msec, TE = 3.8 msec, flip angle = 8°, FOV = 256 x 256, 1 mm3 voxels) was obtained in the same experimental session for anatomical localization of functional findings.

2.5. Behavioral data analysis

Behavioral data were analyzed with the Statistical Package for the Social Sciences, version 19 (SPSS; Chicago, IL, USA). Independent-sample t-tests were conducted to compare the two groups in regards to demographic variables, percentage of correct responses, and response time. Related-samples t-tests were also conducted to compare the percentage of correct responses and response time for the two conditions, general language words and specialized terms.

2.6. ***fMRI data analysis***

The brain images were analyzed using Statistical Parametric Mapping (SPM8) software (Wellcome Department of Cognitive Neurology, Institute of Neurology, Queen Square, London, UK), running under Matlab R2009 (MathWorks, Natick, MA, USA). Pre-processing steps were re-slicing to the mean image of the time series, normalization (using affine and smoothly non-linear transformations) to an EPI template in the Montreal Neurological Institute (MNI) space, and spatial smoothing by convolution with a 3D Gaussian kernel (full width at half maximum (FWHM)= 8 mm).

Two contrasts of interest were defined at the first-level (single-subject) analysis for the tasks: (1) ‘Term>Word’ and (2) ‘Word>Term’. Conditions were modeled for the 8 seconds that each trial appeared on the screen. The BOLD response at each voxel was convolved with the SPM8 canonical hemodynamic response function (using a 128-s high-pass filter). One sample t-tests were conducted to assess intra-group activation in each of the contrasts. Between-group comparisons were conducted with two-sample t-tests on the resulting first-level contrast images. The significance threshold was set at $P < 0.005$ (uncorrected; KE =

10 voxels), which is optimal to achieve an appropriate balance between the risk of error Type I and II (Lieberman & Cunningham 2009).

3. Results

3.1. Behavioral results

Independent-sample t-tests showed significant differences between the groups in regards to the percentage of correct responses when the stimuli were specialized terms (see Table 3). However, no differences were found in the % of correct responses when the stimuli were general language words or in the response time. Related-sample t-tests showed a significantly lower percentage of correct responses and a higher response time for specialized terms than general language words for both groups ($p<0.001$).

Table 3: Percentage of correct responses and response time

	Expert (n = 5) Mean (SD)	**Non-expert (n = 5) Mean (SD)**	**p-value**
Terms (% Correct)	68.23 (3.26)	46.21 (4.30)	0.000 (***)
Response Time (Seconds)	4.117 (0.691)	3.958 (0.729)	0.732
Words (% Correct)	91.00 (9.00)	97.50 (1.40)	0.182
Response Time (Seconds)	2.678 (0.449)	2.646 (0.297)	0.896

SD: Standard Deviation

3.2. Image results

3.2.1. Contrast 1

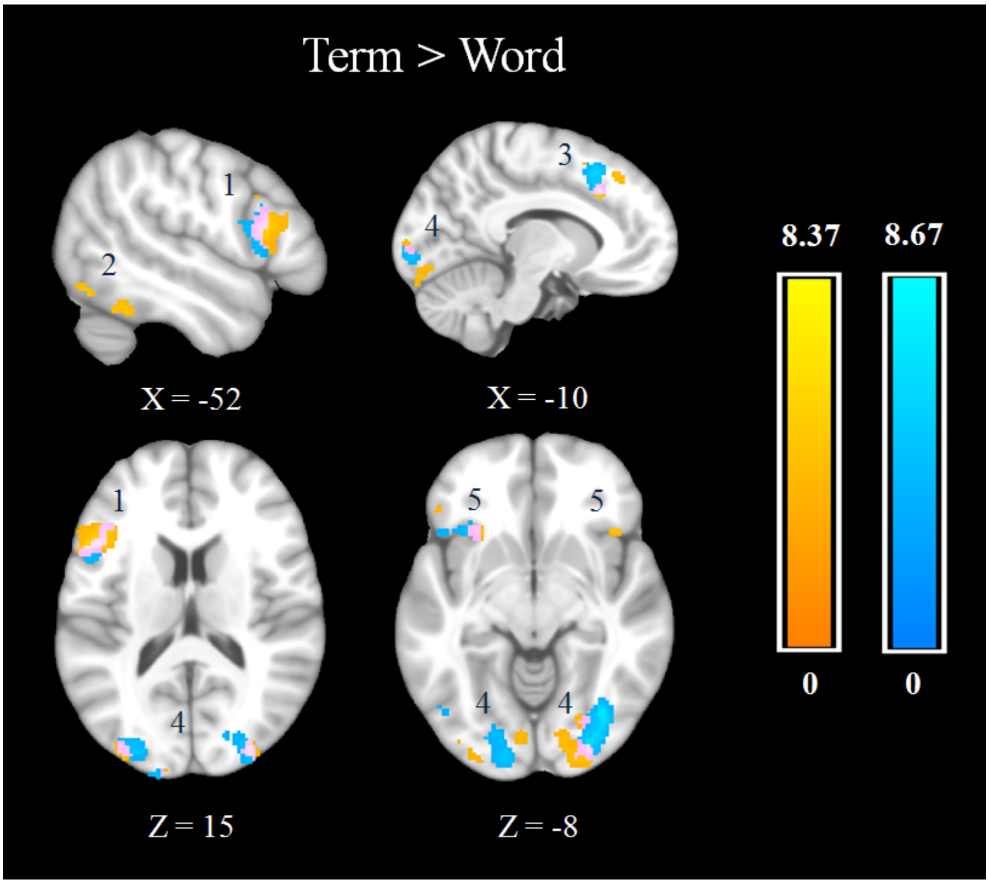
The one-sample t-test showed that when the subjects were asked to link a meaningful attribute with a specialized term (as compared to a general language word), both groups commonly activated the left inferior frontal gyrus (Broca's area), dorsal anterior cingulate gyrus, bilateral anterior insula (only the left for non-experts), superior frontal gyrus, and occipital areas. Notably, experts also activated the inferior temporal gyrus in this contrast as compared to the non-experts.

Table 4: Activations when subjects associated a specialized term with a meaningful attribute

Location	**BA**	**Side**	**x**	**y**	**z**	**Extent**	**Peak T**	**p-value**
Experts								
IFG	44,45	L	-36	18	30	1078	8.26	<0.001
Occipital Lobe	17,18,19	L	-36	-92	8	736	7.64	<0.001
Occipital Lobe	17,18,19	R	32	-88	12	488	7.26	<0.001
Dorsal ACC	32	L	-10	24	36	49	6.78	<0.001

Superior Frontal	8	L	-14	34	50	57	5.88	<0.001
Inferior Temporal	37	L	-54	-50	-20	33	5.10	<0.001
Anterior Insula	13	L	-28	20	-8	57	4.63	0.001
Anterior Insula	13	R	42	22	-8	17	4.42	0.001
Non-Experts								
Occipital Lobe	17,18,19	R	24	-90	4	957	8.67	<0.001
Superior Frontal	8	R/L	-6	16	50	501	7.30	<0.001
ACC	32	R/L	-8	24	38	*	6.35	<0.001
Occipital Lobe	17,18,19	L	-18	-104	10	764	6.22	<0.001
IFG	44,45	L	-44	16	22	711	5.41	<0.001
Anterior Insula	13	L	-34	22	-8	72	4.38	0.001

BA: Brodmann Area; IFG: Inferior Frontal Gyrus; ACC: Anterior Cingulate Cortex. *, Part of the large cluster



1: Inferior Frontal Gyrus; 2: Inferior Temporal Gyrus; 3: Dorsal Anterior Cingulate Cortex/Superior Frontal Gyrus; 4: Occipital Lobe; 5: Anterior Insula

Figure 1: Brain activations during ‘Term > Word’ contrast [Warm colors reflect expert group and cold colors reflect non-expert group. Purple reflects overlap of both groups. X and Z denote coordinate in standard MNI space. Right hemisphere is displayed on the right. Color bar indicates T value.]

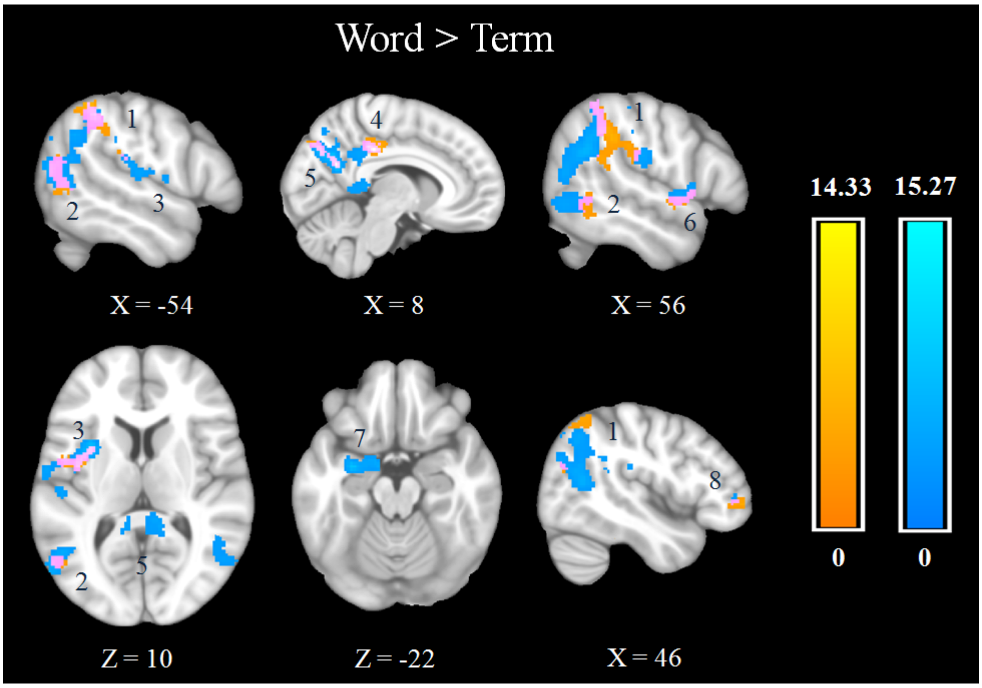
3.2.2. Contrast 2

For contrast 2, the association of a meaningful attribute with a general language word in comparison to a specialized term significantly activated the posterior cingulate cortex, precuneus, bilateral middle temporal gyrus, angular and supramarginal gyrus, right orbitofrontal gyrus, superior temporal gyrus, and left posterior insula. As explained in the discussion section, these are areas related to episodic memory, knowledge of tools, supramodal integration of semantic concepts, and visual word recognition. Non-experts also activated the left amygdala, which could indicate that the general language words had some type of emotional valence for them (which was not the case for the specialized terms). In regards to the experts, since their amygdala activation was similar to that in Contrast 1, it does not appear in the results.

Table 5. Activations when subjects associated a general language word with one of its attributes

Location	Side	BA	x	y	z	Extent	Peak T	p-value
Experts								
PCC	R/L	31	8	-30	36	756	14.45	<0.001
Supramarginal gyrus	L	40	-62	-30	34	709	12.69	<0.001
Posterior Insula	L	13	-38	-2	10	234	9.81	<0.001
Precuneus	R/L	7	12	-76	40	228	7.60	<0.001
Middle Temporal	L		-50	-62	4	215	6.89	<0.001
Supramarginal gyrus	R	40	60	-44	48	800	6.76	<0.001
Superior temporal	R	22	52	6	-6	180	6.23	<0.001
OFC	R	46	46	52	-2	111	5.28	<0.001
Middle Temporal	R	37	62	-56	-4	173	4.65	0.001
Non-Experts								
Precuneus	R/L	7	8	-60	24	2599	15.39	<0.001
PCC	R/L	31	6	-32	36	*	8.69	<0.001
Posterior Insula	L	13	-32	-18	14	2991	13.58	<0.001
Angular gyrus	L	39,40	-62	-32	32	*	11.09	<0.001
Amygdala	L		-30	-4	-18	*	8.19	<0.001
Middle Temporal	L		-50	-60	6	*	6.13	<0.001
Middle Temporal	R	37	62	-58	-6	259	7.14	<0.001
Angular gyrus	R	39,40	56	-42	36	2439	6.80	<0.001
Superior temporal	R	22	50	-60	18	*	6.30	<0.001
OFC	R	46	34	42	-2	53	5.70	<0.001

BA: Brodmann Area; PCC: Posterior Cingulate Cortex; OFC: Orbitofrontal Cortex. *, Part of the large cluster



1: Angular/Supramarginal Gyrus; 2: Middle Temporal Gyrus; 3: Posterior Insula; 4: Posterior Cingulate Cortex; 5: Precuneus; 6: Superior Temporal Gyrus; 7: Amygdala; 8: Orbitofrontal Cortex.

Figure 2: Brain activations during 'Word > Term' contrast. [Warm colors reflect expert group and cold colors reflect non-expert group. Purple reflects overlap of both groups. X and Z denote coordinate in standard MNI space. Right hemisphere is displayed on the right. Color bar indicates T value].

3.2.3. Direct between-groups comparison

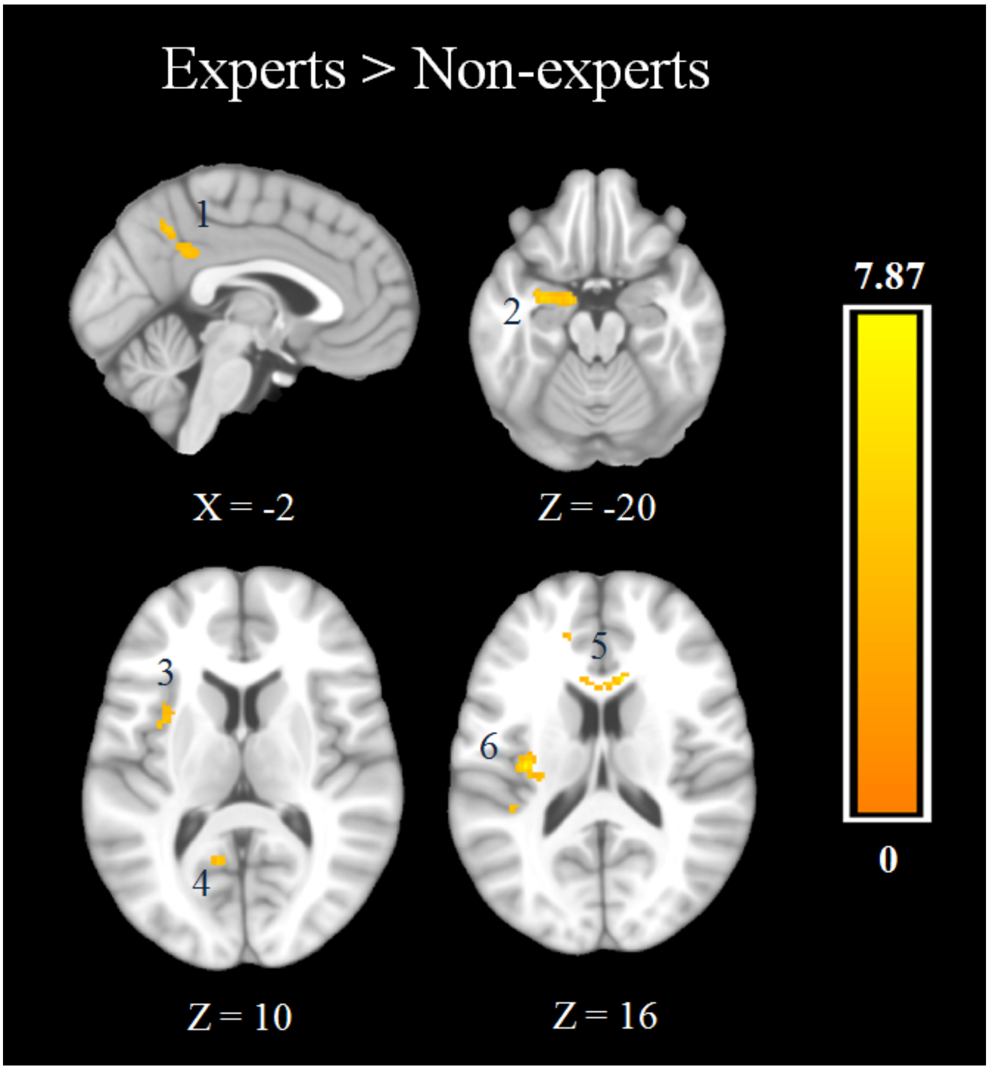
The direct between-groups comparison showed that expert participants had increased activation of the anterior (ACC) and posterior cingulate cortex (PCC), precuneus, left anterior and posterior insula, and left parahipocampal gyrus extending to the amygdala when they had t associate a meaningful attribute with a specialized term as compared to a general language common word. As explained in Section 4, these are areas that are all linked to high-level cognitive functions, such as semantic decision-making (IFG, insula), executive control and attention (ACC, precuneus), problem-solving (ACC, insula), semantic integration (PCC), and episodic/autobiographic memory retrieval (PCC, precuneus, and amygdala).

Table 6. Areas of greater activation in experts than in non-experts in the specialized term meaning association task in comparison to the general language word meaning association task

Location	Side	BA	x	y	z	Extent	Peak T	p-value

Posterior Insula	L	13	-32	-18	14	85	7.66	<0.001
Amygdala / Parahipocampal gyrus	L	34	-30	-4	-18	129	7.45	<0.001
Precuneus	R	31	8	-60	24	41	7.30	<0.001
Posterior Insula	L	13	-40	-34	18	30	6.12	<0.001
PCC	R/L	31	-12	-48	34	193	5.73	<0.001
Anterior Insula	L	13	-34	4	10	76	4.74	0.001
ACC	R/L	32	-14	44	14	12	4.49	0.001

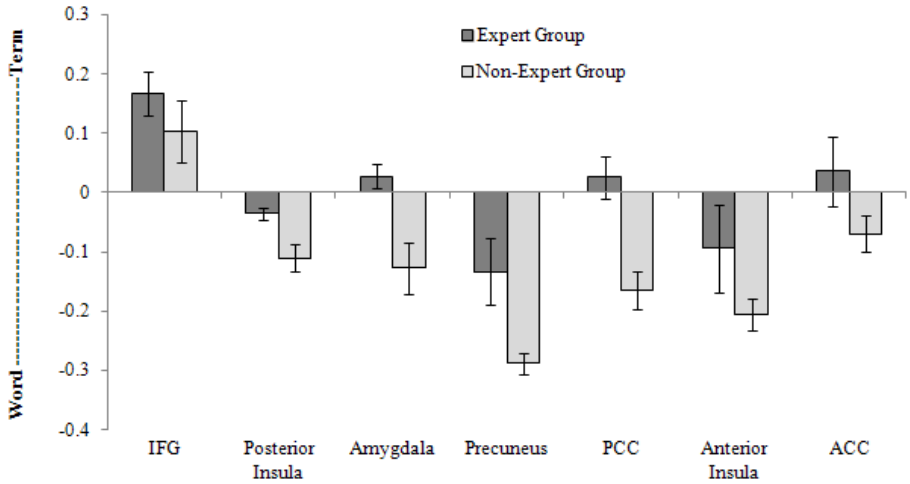
BA: Brodmann Area; PCC: Posterior Cingulate Cortex; ACC: Anterior Cingulate Cortex. *, Part of the large cluster



1: Precuneus/Posterior Cingulate Cortex; 2: Amygdala; 3: Anterior Insula; 4: Precuneus; 5: Anterior Cingulate Cortex; 6: Posterior Insula

Figure 3: Brain group differences. [X and Z denote coordinate in standard MNI space. Right hemisphere is displayed on the right. Color bar indicates T value].

Figure 4: Brain activations extracted from areas significant different in the between group comparison and IFG during 'Term > Word' contrast.



4. Discussion

4.1. Contrast 1: Association between specialized term and meaningful attribute

In this contrast, we explore the brain areas with a higher activation when subjects were asked to associate a specialized term with a meaningful attribute (compared with a general language word) as a way of verifying their understanding. In this task, both groups showed significant activation in the occipital lobes. This was not surprising since the occipital lobes are the seat of the primary visual cortex, which receives and interprets information from the retinas.

Accordingly, both expert and non-expert subjects also activated the superior frontal cortex (BA 8), which includes the frontal eye fields. Apart from its connection to vision, this brain region has been linked to the management of uncertainty (Voltz *& al*. 2004). The uncertainty inherent in this task could very well be internally attributed and based on introspective confidence or knowledge level. Since a successful coping strategy for uncertainty is an intensive memory search, this seems to fit the task demands. Brain activation in this area was similar between groups since both experts and non-experts were trying to access semantic representations and identify the devices, based on their knowledge of attributes. The fact that experts were able to accomplish this task more successfully is reflected in the percentage of correct answers (see Table 3).

As expected, both groups also experienced activation in the following areas: (i) left inferior frontal gyrus (IFG), devoted to language processing and production; (ii) the dorsal anterior cingulate gyrus used for executive control and attention; (iii) bilateral anterior insula used for problem-solving and decision making.

However, only the expert subjects activated the inferior temporal gyrus (ITG). As a component of the visual cortex, this brain area is part of the ventral visual pathway, which identifies what things are and helps to integrate information from different senses. According to Binder *& al*. (2009), the ITG is part of the heteromodal cortex involved in supramodal integration and concept retrieval. Noppeney *& al*. (2007) highlight that ITG activation is frequently reported during semantic retrieval or naming tasks in functional imaging studies. The fact that the same representation is triggered, regardless of whether the stimulus format is a word or picture (Shinkareva *& al*. 2011) seems to lend support to the existence of a supramodal semantic representation, which acts as a template for the integration of perceptual information.

It was hypothesized that only the expert group would show activation in this brain area since these subjects were familiar with the specialized term as well as with the object designated. It has been posited that certain aspects of meaning reside in the medial and inferior temporal cortex, where specific temporal areas are activated by words conveying different kinds of visual information (Pulvermüller & Fadiga 2010). This indicates that the experts (unlike the non-experts) were aware of what the specialized instrument looked like, and thus were able to access this information and interpret it correctly.

Finally, there was activation in the anterior insula. As one of the most frequently activated regions in neuroimaging research, this brain area is instrumental in a broad range of cognitive domains (Chang *& al*. 2013), such as problem solving and decision-making related to challenging tasks (Binder 2004). More specifically, the anterior insula has been found to play a role in domain-general attentional control and decision-making (Thielscher & Pessoa 2007), whereas the posterior insula is instrumental in sensorimotor processing (Chang 2013). In fact, as shall be explained (Section 4.3), the insula is also a key area in language processing (Ardila 2014).

4.2. Contrast 2

In Contrast 2, in which the subjects processed general language words, the posterior cingulate cortex (PCC) was activated by both groups, as was the precuneus. Both brain areas play an important role in the retrieval of episodic memory such as those related to personal experience or contexts in which the subjects used the instruments.

Activation also took place in the left posterior middle temporal gyrus (pMTG), which is an important area for semantic cognition (Binder *& al*. 2009; Vigneau *& al*. 2006). Although, as highlighted by Hoffman *& al*. (2012), the pMTG has been found to be strongly activated when retrieving knowledge of tools (Martin 2007), another possibility is that the pMTG is involved in the executive control processes that regulate access to conceptual knowledge (Whitney *& al*. 2011). Turken & Dronkers (2011) even go so far as to elevate the MTG to the status of a semantic hub for a broad network of brain areas (angular gyrus, superior temporal gyrus, and frontal area BA 47). The anterior temporal lobe thus acts as an integrative hub in which the spokes are connections to modality-specific cortices (Patterson *& al*. 2007).

There was also activation of the tempoparietal junction with the two largest Brodmann areas 40 and 39, roughly corresponding to the supramarginal (SMG) and angular gyri (AG), respectively (Rushworth *& al*. 2006). Both regions have been found to play an important role in visual word recognition and understanding. More specifically, SMG activation occurs when the focus is on the sound of a word, whereas AG activation is more focused on word meaning (Price *& al*. 1997).

AG activation is also in line with the account of heteromodal semantic processing known as the hub-and-spoke model of the anterior temporal lobe. Nevertheless, there appear to be various heteromodal association areas centered on the angular gyrus in the parietal lobe and running the entire length of the temporal lobe at points where modality-specific processing pathways converge (Bonner *& al*. 2013). Research indicates that the angular gyrus is essential to concept representation (Binder *& al*. 2009). Quite possibly, all subjects activated convergence zones in which the information regarding tools was integrated to form a more or less complete semantic representation of the concept designated by the word.

Both experts and non-experts activated the right superior temporal gyrus (STG) (BA 22). Nevertheless, although language processing is believed to take place primarily in the left hemisphere, there is increasing evidence that the role of the right hemisphere has been overlooked (Donnelly *& al*. 2011), apart from RH involvement in the decoding of contextual information, metaphor, discourse meaning, and jokes (Beeman & Chiarello 1998). Although the right STG has been linked to the discrimination of pitch and sound intensity (Berbal & Ardila 2014), it is now thought that it may be activated for other tasks as well. Regarding the task in our study, it was posited that the contribution of the STG was related to executive processing, namely the recruitment of attentional and working memory areas (Vigneau *& al*. 2011) and/or the integration or association of semantic concepts (Graves *& al*. 2010).

Both experts and non-experts also showed activation for this task in the orbitofrontal cortex (OFC) (BA 46), an area involved in memory as well as memory control and organization. More specifically, this area has also been implicated in a wide range of cognitive functions linked to relational memory encoding (Murray & Ranganath 2007). In contrast 2, the left posterior insula was activated since it is involved in sensorimotor processing as well as lexical knowledge, word retrieval, language understanding, and phonological discrimination (Ardial *&* *al*. 2014).

4.3. *Direct between-groups comparison*

In the direct comparison between groups, the areas of greater activation in experts when associated a specialized term with a meaningful attribute (compared with a general language word) were the following: the inferior frontal gyrus (IFG), precuneus, anterior and posterior insula, the left anterior (ACC) and posterior cingulate cortex (PCC), and the left parahipocampal gyrus extending to the amygdala.

The IFG (BA 44, 45) is closely associated with verbal semantic processing (Binder *&* *al*. 2009) and has been found to have an important role in on-line semantic search during effortful semantic processing, such as the selection and retrieval of semantic knowledge (Fan *&* *al*. 2010). It is prominent in semantic decision-making (Xaio *&* *al*. 2005) as well as in tasks involving verb generation (van Oers *&* *al*. 2005). It is also well connected to posterior semantic representation systems in the inferior and temporal areas, from where it selects semantic representations (Badre & Wagner 2007). Activation was greater because the experts (unlike the non-expert) accomplished the task involving specialized terms more successfully, thus being able to find the corresponding semantic representations stored in posterior brain areas.

Another brain area activated more prominently by experts was the anterior cingulate cortex (ACC). In this case, activation took place in BA 32, which is commonly subdivided into several anterior and dorsal subregions (Vogt 2009; Vogt *&* *al*. 2004). This area of the brain plays a pivotal role in domain-general executive control (Gasquoine 2013). Precisely for this reason, a wide range of different functions has been attributed to it, namely, attention (Weissman *&* *al*. 2005), performance monitoring (Hewig *&* *al*. 2011), and response selection (Schultz *&* *al*. 2011). Furthermore, according to Weston (2012), an additional function of the ACC is the representation of what needs to be done to successfully complete a task. This makes it possible to plan, organize, and implement behaviors matching those requirements. As part of distributed networks, the contribution of the ACC is directly related to problem solving since it engages in the coordination and organization of processing in other brain regions to efficiently achieve consummation, and thus implement an optimal strategy.

Another brain area in which there was a significant activation difference in experts and non-experts was the insula. Although the insula has rarely been linked to language, Ardila *& al*. (2014) underline that it is a key language area, including both language comprehension and production. More specifically, the anterior segment interfaces with Broca's area (Bonilha & Fridriksson 2009) and its posterior elements extend to Wernicke's area (Flynn *& al*. 1999). The insula is also connected to BA 9, an area involved in complex language processes and to BA 37 (lexico-semantic associations). Greater activation in this area by experts in relation to terms seems logical because of the complex nature of the decision-making task, which involved the retrieval of semantic representations and the subsequent identification of semantically related words.

Greater activation also occurred in the posterior cingulate cortex (PCC). According to Leech & Sharp (2013), the PCC is part of the posteromedial cortex. Based on its close connection other brain regions, it has been posited as a potential candidate hub for information processing (Hagmann *& al*. 2008). It has also been said to support internally directed cognition involving the retrieval of autobiographical or episodic memories. According to Sugiura *& al*. (2005), personally familiar objects and places play an important role in such episodes. This was evidently the case for all of the subjects, but to a much greater extent for experts

The precuneus was also strongly activated by experts. Similarly to the PCC, activations in this brain area have been consistently observed in studies of episodic memory (Utevsky *& al*. 2014). Precuneal activity has also been linked to visuo-spatial imagery (Suchan *& al*. 2002), and self-processing (Kjaer *& al*. 2002). According to Cavanna & Trimble (2006), these behavior correlates all stem from the mental representation of the self and internally guided attention. This is further supported by the fact that the precuneus appears not to have any direct connections with primary sensory regions. Its activity thus seems to influence an extensive network of cortical and subcortical structures involved in elaborating integrated and associative information, rather than processing external stimuli (Cavanna & Trimble 2006). This seems to indicate that a subject's personal experience with the object modulates the neural processes called upon during comprehension (Lyons *& al*. 2010).

Finally, another important area of activation was the parahippocampal gyrus extending to the amygdala. As an important region of the limbic system, its main function involves memory creation and recall of visual scenes. According to Bar *& al*. (2008), the parahippocampal gyrus encodes context (objects that typically co-occur in the environment), and responds more strongly to scenes with rich contextual associations.

Activation in this area extended to the amygdala, the region of the integration of emotion and cognition in the brain as well as the integration of both to achieve behavioral goals. Although the amygdala is generally linked to emotional processing, it is now known to have an important role in many behavioral functions. These functions include the retrieval of autobiographical memory (Markowitsch & Staniloiu 2011) and even lexical semantic decision-making (Nakic *& al*. 2006). Given its connectivity to other areas, the amygdala is said to facilitate the integration of emotive and cognitive functions (Pessoa 2008). Our results seem to confirm that lexical decisions were more accurate for terms with an emotional valence because their semantic representations stored in a distributed network of cortical regions in the temporal cortex received reciprocal feedback from the amygdala (Nakic *& al*. 2006).

Even though terms for scientific instruments are not typically regarded as having emotional valence, this could depend on the subjects' past experience. Objectively seemingly neutral information may be processed in an affective manner because of its self-relevance (Rameson *& al*. 2010). For example, in the case of experts, such instruments could activate affectively charged memories of personal life events. Autobiographical memory retrieval differs from episodic memory retrieval in the emotional arousal associated with the event (Greenberg *& al*. 2005). Our results seem to indicate that the amygdala is involved in this process, particularly since it is interconnected with the other frontotemporal components implicated in autobiographical memory.

5. Conclusions

This pilot study has repercussions for Terminology and the representation of specialized knowledge. There has been considerable discussion on how to model concepts and their relations within a specialized knowledge field. Although there is a certain consensus that this representation should emulate the organization of semantic information in the brain, it is necessary to obtain neurological data that can provide insights into semantic processing as well as concept storage and retrieval.

Given the small size of the sample, the results obtained in this study are not definitive, though this limitation is partly compensated by the homogeneity of the subjects. Interestingly, our results support that expert knowledge involves a supramodal conceptual representation. In this sense, the brain activations in our study appear to be in consonance with Fairhall & Carramazza (2013), who found a network of six left lateralized regions largely outside of category-selective visual cortex that showed a supramodal representation of object categories. Accordingly, this research also supports the PC and pMTG/ITG as candidate regions for the supramodal representation of the conceptual properties of objects.

In Terminology, the correlate of this supramodal representation is a category schema or template as posited by various authors (Faber 2012; Roche *& al*. 2009; Leonardi 2010; Temmerman 2000). In neurology, this relates to the 'embodied abstraction view' of Binder & Desai (2011) in which conceptual representation has multiple levels of input. The top level consists of schematic representations that are fleshed out by sensory-motor-affective input when and as needed. These modality-invariant representations have been compared to geographic maps (Lambon Ralph *& al*. 2010), in which each map type (geological, political, linguistic, etc.) codes the same chart/grid system, but differs in the presence or absence of each type of feature.

Based on the brain areas activated by experts, another characteristic of specialized knowledge processing seems to be the vital role played by contextualization and situation. A set of regions consistently overlapped in the contrasts, namely, the bilateral precuneus, posterior cingulate, and insula. It is no accident that all three regions have previously been implicated in mental imagery, episodic memory, and context representation. This indicates the crucial role of visual information at the level of situation. The importance of visual scene generation is reinforced by brain activation in the parahippocampal gyrus, which encodes meaningful contextual associations.

In Terminology, the vital role of context and of embedding concepts in situations has also been highlighted (Dubuc & Lauriston 1997) as a way of enriching conceptual representations (Faber 2012; Temmerman 2013). Although context is often regarded as the segment/s of a written or spoken statement which precede or follow a word or phrase, it can also be a related situation, events, or information that help users to understand something, and which reflect a specific knowledge profile. This type of information is specific of each user and is a key factor in contextual considerations that modulate knowledge base access and use. The explication of contexts should take place at multiple levels that range from concept to frame.

Much of the network in Binder & Desai (2011), which was also activated by the experts in our study, has been implicated in the retrieval of episodic and autobiographical memories. The hypothesis is that these regions retrieve event memories through a process of scene construction. These results validate the need to include contextual information in terminological knowledge bases and thus facilitate the process of scene creation in the non-expert. This can be accomplished by providing multimodal contextual information, which include but are not limited to visual images, related concepts, and even auditory information. More concretely, different types of perceptual input should enhance the generalization and abstraction process that contributes to the integration of new information in semantic memory. This makes it possible for semantic memory to recreate scenarios the non-expert has never been involved in.

Finally, the results of this study give support to the hypothesis that when performing a domain-specific task, experts activate different brain systems from those activated by novices. The systems for expert knowledge processing and representation seem to be directly related to the activation of supramodal representations recovered from the temporal area as well as to visual scene generation encoding meaningful contexts. This highlights the need to include category templates, knowledge-rich contexts, and multimodal information in terminology knowledge bases.

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